Images of VLBI Calibrators from the BeSSeL Survey

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Abstract The BeSSeL Survey is a VLBA Key Science project. The primary goal of the survey is to study the spiral structure and kinematics of the Milky Way, by measuring distances and proper motions to masers in regions of massive star formation across large portions of the Milky Way. To measure the distances of Masers via trigonometric parallaxes, the relative positions between the masers and extragalactic VLBI calibrators are determined with phase-referencing at different epochs spanning at least one year. The Masers usually serve as phase reference since they are much stronger than the calibrators, allowing integration times about one hour for the weak calibrators. In addition, the calibrators are often observed through the whole observing program, providing excellent uv-coverage for imaging. From the BeSSeL survey, there will be about 4,000 high-quality images of about 200 VLBI calibrators distributed near the Galactic plane. In this report, we present basic information of the VLBI calibrator images from the BeSSeL survey.

Keywords VLBI, calibrators, astrometry, phase referencing

1 Introduction

Calibrators are important for both absolute and relative VLBI astrometry. For absolute astrometry, VLBI calibrator surveys will help to improve the International Celestial Reference Frame (ICRF), by adding new sources (i.e., QSOs) to densify the grid of the frame and monitoring the mass structures of the current sources. The space astrometry satellite Gaia has an ambitious aim to construct a dense optical celestial reference frame based on QSOs with unprecedented position accuracy. Aligning the Gaia frame to the ICRF with the highest accuracy will be crucial for ensuring consistency between the measured radio and optical positions. However, only a small number of the current ICRF sources are suitable for this alignment, more common sources from a calibrator survey are important for the optical and radio frame link [2].

For relative astrometry, the achievable accuracy of a differential VLBI measurement is approximately proportional to the angular separation between the calibrator and the target [5]. In other words, the relative astrometry accuracy and image quality of the weak radio source using phase-referencing relies on a dense and accurate grid of bright radio sources [4].

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2 VLBI Calibrators

2.1 VLBI Calibrators from Absolute Astrometry

Currently there are about 10,000 calibrators and 45,000 images of 8,000 calibrators (http://astrogeo.org). However, most of the calibrators are from absolute astrometry and geodesy programs in snapshot observing mode, which observe the calibrators for a few scans with minutes of integration time. The primary Web sites of image database VLBI calibrators are listed below,

- Radio Reference Frame Image Database (RRFID)
  URL: http://rorf.usno.navy.mil/rrfid.shtml

The RRFID contains snap-shot VLBA S/X band and K/Q band images and some LBA X band images.

- Bordeaux VLBI Image Database (BVID)
  URL: http://www.obs.u-bordeaux1.fr/m2a/BVID
  The BVID contains a total of 4,499 VLBI images of 1,212 extragalactic radio sources, including VLBI images at S/X and K/Q band.
- Astrogeo VLBI Image Database
  URL: http://astrogeo.org
  On this Web site, the VLBI image database of compact radio sources provides 45,000 images of active galactic nuclei in radio waves, including images from many calibrator surveys using the VLBA, EVN, KVN, KaVA, and LBA.

2.2 VLBI Calibrators from Relative Astrometry

For relative astrometry, phase referencing is one of the most important observing modes which observe a weak target and one or more nearby calibrators alternately or simultaneously, using the derived delay, delay rate, and phase corrections from the calibrators to remove their effects from the target source visibility, increasing the integration time to hours for weak target sources. This technique allows relative position measurements of target–calibrator source pairs, and imaging weaker objects [1]. VLBI phase-referencing is widely applied in a wide range of astrophysics studies and space navigation. However, currently there are no image databases for calibrators from VLBI relative astrometry, i.e., phase-referencing.

3 Calibrators from the BeSSeL Survey

3.1 BeSSeL Survey

The BeSSeL Survey (Bar and Spiral Structure Legacy Survey) is a VLBA Key Science project. Detailed information about BeSSeL can be found on its Web site (http://bessel.vlbi-astrometry.org). The primary goal of the survey is to study the spiral structure and kinematics of the Milky Way, by measuring distances and proper motions to masers (6.7 and 12 GHz CH_3OH and 22 GHz H_2O masers) in regions of massive star formation across large portions of the Milky Way. To measure the distances of masers via trigonometric parallaxes, the relative positions between the masers and extragalactic VLBI calibrators are determined with phase-referencing at different epochs spanning at least one year. As shown in Figure 1, over 100 distances to high-mass star-forming regions have been measured with trigonometric parallaxes by the VLBA, VERA, and EVN [6]; the shapes and widths of the spiral arms of the Milky Way were determined by these measurements.

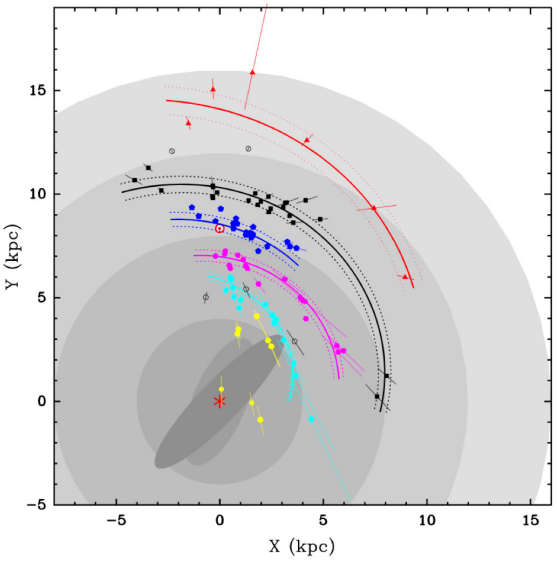

Fig. 1 Plane view of the Milky Way showing the locations of high-mass star forming regions with trigonmetric parallaxes measured by the VLBA, VERA, and the EVN [6].

An important byproduct of the BeSSeL survey would be the images of VLBI calibrators. Except for searching new calibrators in snapshot mode [3], BeSSeL also monitors many VLBI calibrators at different frequencies and different epochs. The masers usually serve as phase reference since they are much stronger than the calibrators, allowing several hours' integration times for the weak calibrators. In addition, the calibrators are often observed throughout the whole observing program, providing excellent uv-coverage for imaging. Therefore, BeSSeL will provide a high

quality VLBI calibrator image database, which is very important for astrometric and astrophysical studies.

3.2 BeSSeL Calibrators

There are about 200 VLBI calibrators observed in BeSSeL, and about 40% of them have no VLBI images. For each calibrator at different frequencies, there are at least four images obtained at different epochs spanning at least one year. There are about 130 and 110 calibrators to be observed at K- and C-band, respectively. Whereas for Ku band, there are about 15 calibrators. For some calibrators, the numbers of observing epochs are larger than 60. In total, BeSSeL has about 500 VLBA programs at different epochs as shown in Table 1. For each epoch, there are about eight calibrators. Thus, there are about 4,000 images for all calibrators.

Table 1 BeSSeL VLBA programs.

Program code	Sub-code	Epochs	Freq. Band	Time range
BR145	B-Y	189	K/Ku	2010.4–2013.12
BR149	B-U	83	K	2012.9–2014.4
BR198	A-V	131	C/K	2013.9–2015.4
BR210	A-F	96	C/K	2015.2–2016.10

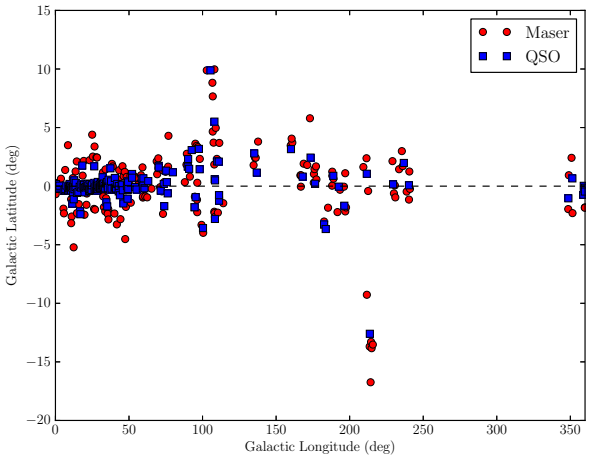

Fig. 2 Sky distribution of Maser sources and calibrators from the BeSSeL survey in Galactic coordinates.

3.2.1 An Example of VLBI Calibrator Images

Here, we show an example of the calibrator images from VLBI phase-referencing observations under the VLBA program BR198C4 at C-band (6.7 GHz). In this program, we observed three group of target and calibrators. Figure 3 shows the sky distribution of one target and three calibrators in the first group.

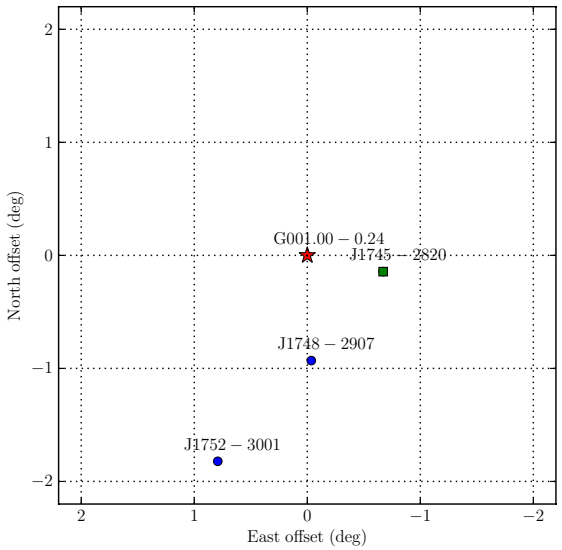

Fig. 3 Relative position of target and calibrators in an example of VLBI relative astrometry under the VLBA program BR198C4.

In this program, we obtained the first VLBI image of J1752-3001, and the first images of J1745-2820 and J1748-2907 at C-band (6.7 GHz). The image qualities of the latter two are much better than their previous images, mainly due to the better uv-coverage and longer integration time of about one hour. The RMS noise in the images, as shown in Figure 4, is close to the theoretical thermal noise. Figure 5 shows the correlated flux densities of the calibrators versus the uv-distance, which indicates the compactness of the radio sources.

4 Future Work

We started to create images of the VLBI calibrators in early 2016. We plan to finish the imaging of all BeSSeL VLBI calibrators close to the galactic plane by the end of 2016, and then the remainder by July 2017. There

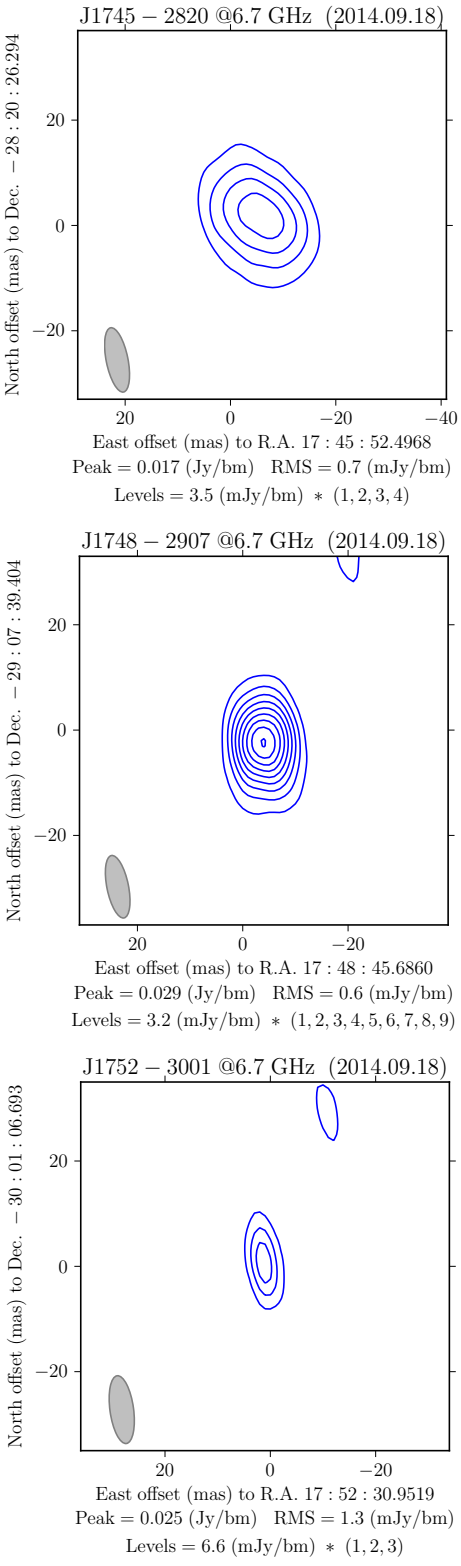

Fig. 4 VLBI images of three calibrators at C-band on 18 September 2014 under the VLBA program BR198C4.

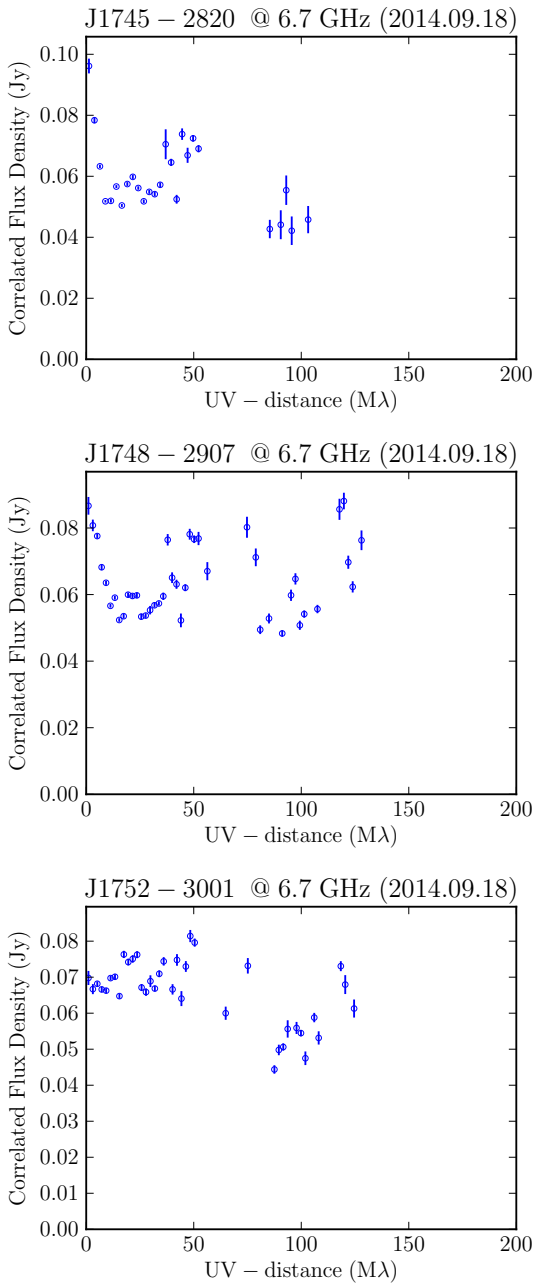

Fig. 5 Correlated flux versus uv-distance of three calibrators at C-band on 18 September 2014 under the VLBA program BR198C4.

are also some BeSSeL-like phase-reference VLBI program archived data from the VLBA, VERA, and the EVN. The images from these archived data are also very important for monitoring the source structures. We will make images for these calibrators in the future.

Acknowledgements

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References

1. Beasley, A. J. & Conway, J. E. 1995, in Astronomical Society of the Pacific Conference Series, Vol. 82, Very Long Baseline Interferometry and the VLBA, ed. J. A. Zensus, P. J. Diamond, & P. J. Napier, 327.
2. Bourda, G., Charlot, P., & Le Campion, J.-F. 2008, A&A, 490, 403.
3. Immer, K., Brunthaler, A., Reid, M. J., et al. 2011, ApJS, 194, 25.
4. Petrov, L., Kovalev, Y. Y., Fomalont, E. B., & Gordon, D. 2008, AJ, 136, 580.
5. Reid, M. J. & Honma, M. 2014, ARA&A, 52, 339.
6. Reid, M. J., Menten, K. M., Brunthaler, A., et al. 2014, ApJ, 783, 130.